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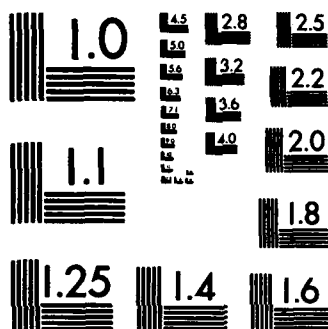
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ACOUSTICAL PROCESSES IN MARINE SEDIMENTS
ANNUAL REPORT UNDER CONTRACT N00014-76-C-0117

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes work carried out in 1982 under Contract N00014-76-C-0117. Research included: (1) theoretical analyses of propagation in gassy sediments and reflection from porous marine sediments, (2) laboratory measurements of the properties of shear and compressional waves for comparison to predictions of the Biot theory, and (3) design of an experiment to measure the acoustical properties of hydrated marine sediments.		

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I. INTRODUCTION

Since January 1971, Applied Research Laboratories, The University of Texas at Austin (ARL:UT), has conducted an ongoing research program funded by the Office of Naval Research (ONR) to study the propagation of acoustical waves in ocean bottom sediments. The thrust of the program has been the study of acoustical properties of marine sediments by means of a coordinated program of measurements of sediment parameters coupled to theoretical efforts to understand and predict these parameters. A major part of the earlier efforts of the program was the development of techniques and equipment to make accurate and inexpensive in situ acoustical measurements during routine geophysical coring. These have been successfully used in at-sea measurements. Another important product of the program was the development of a new type of transducer element for shear wave measurements in low rigidity media, which makes possible both laboratory and in situ measurements of shear wave properties of unconsolidated sediments. A patent has been issued for this transducer. More recently, the program has shifted away from an emphasis on in situ measurements and is now oriented toward a combination of laboratory measurements closely coupled to theoretical analysis. The ARL:UT program has as one of its objectives the development of competent researchers capable of pursuing careers in scientific and technological areas of interest to the Navy. This objective is being achieved through continuing involvement of faculty and graduate students from The University of Texas at Austin. Publication of research results has also been an important goal in the program. A total of 54 reports, journal articles, and oral presentations have been produced, including 12 papers published in scientific journals, three articles included in books, three invention disclosures submitted for patent, and one patent issued. The Appendix is a cumulative listing of this documentation.

The current emphasis of the ARL:UT program on an integrated experimental and theoretical program has come about for several reasons. First, the in situ profilometer and shear wave transducer have reached mature stages of development and no longer require a major effort at the basic research level. Second, equipment and procedures for conducting acoustical measurements on laboratory samples of sedimentary material, natural or synthetic, were developed at ARL:UT as a necessary part of the design process of the profilometer and shear wave transducer. Third, there are a number of concurrent 6.1, 6.2, and 6.3 research projects at ARL:UT for which the acoustics of marine sediments is an important issue. Current 6.1 projects include: normal mode modeling of propagation in shallow water (ONR 425AC), nonlinear acoustics of sedimentary material (ONR 400R), and the relation between mechanical and acoustical properties of marine sediments (ONR 400R). In the 6.2 area, these include the programs in bottom interaction (NAVELEX 612/NORDA 110A), high frequency (NAVSEA 63R/NORDA 110A), and mine countermeasures (ONR Code 425AR). In the 6.3 area, these include work sponsored by the SEAS (NORDA 520) and TAEAS (NORDA 530) programs such as: bottom loss upgrade (SEAS and TAEAS), measurement planning and analysis (SEAS), array characterization (SEAS), and broadband propagation (TAEAS). These projects not only identify gaps in basic research, but are ready customers for results from the ONR 425GG program. Finally, the research staff at ARL:UT and several academic departments at The University of Texas at Austin have worked on closely related problems, have considerable theoretical and experimental expertise to bring to the sediment acoustics problem, and are interested in contributing to the ARL:UT program on a continuing basis.

In 1982 the ARL:UT program worked in three areas, and the results have been published in technical journals or as ARL:UT technical reports. The first area was theoretical analyses of two subjects: (1) propagation in sediments containing gas bubbles and (2) the comparison of Biot and viscoelastic treatments of reflection from

sedimentary material. A journal article on the first subject was recently published, while work on the second is still in progress. The second major research area was an experimental program to verify various aspects of the Biot treatment of propagation in marine sediments; in particular, the dependence of shear and compressional velocities and absorptions on viscosity was measured and compared to Biot theory predictions. Preliminary results of these measurements have been described in a paper that was submitted for journal publication. The third major area was the design of an experiment to measure the acoustical properties of hydrated marine sediments. The design has been completed and is described in a report. The progress of each of these areas is briefly described in the following section.

II. THEORETICAL ANALYSES

A. Wave Propagation in Gassy Sediments

It is well known that the presence of a small volume of gas bubbles in a liquid can greatly alter the velocity and attenuation of acoustic waves in the liquid.¹⁻³ Evidence is beginning to accumulate that the velocity and attenuation of acoustic waves in a saturated marine sediment can be affected by the presence of gas bubbles in the saturating liquid.^{4,5} The most complete existing model for wave propagation⁶⁻¹⁰ in saturated marine sediments is based upon the theory of Biot.^{11,12} The sediment is modeled as a binary mixture of an elastic or viscoelastic solid saturated by a compressible fluid, and the effects of the relative motion of the solid and fluid are included. This model has been shown to predict the phase velocity and attenuation of compressional and shear waves in saturated sediments over a broad range of frequencies. The Biot equations have also been used to model porous rocks saturated by a liquid containing gas bubbles¹³⁻¹⁶ by assuming the porous solid to be saturated by a single fluid whose properties were determined by averaging the properties of the liquid and gas constituents.

During 1982, research was performed to model a gassy sediment as a three-constituent mixture: solid, liquid, and gas. This work is described in detail in a journal publication.¹⁷ Briefly, a variational method of deriving equations of motion for mixtures is used to obtain a theory for a granular sediment saturated by a liquid which contains bubbles of gas. The theory is an extension of the Biot approach to wave propagation in saturated sediments. Wave velocity and attenuation are determined for a model of water-saturated sediment containing a small volume of air bubbles. It is verified that the model predicts the

qualitative features that have been observed experimentally in gassy sediments. At frequencies below the bubble resonance frequency (BRF), the phase velocity is substantially decreased by the presence of the bubbles. Near the BRF, the attenuation increases markedly. Above the BRF, the phase velocity and attenuation approach the values which they would have if no bubbles were present.

B. Reflection and Transmission Studies

A major drawback of past studies of wave propagation in saturated sediments is that they are restricted to relatively high (ultrasonic) frequencies. As a result, an important unresolved question is whether the Biot-Stoll model⁶⁻¹² predicts the attenuation of waves at low frequencies.

One approach to this question would be to compare theoretical results from the Biot-Stoll model to at-sea measurements of bottom loss at low frequencies. In order to do this, it is necessary to solve the problem of the reflection and transmission of incident waves at the water-saturated sediment interface. There are two other motivations for solving the reflection and transmission problem. First, the results can be compared with corresponding solutions obtained by modeling the sediment as a viscoelastic material, and it can be determined whether the latter approach is acceptable or under what circumstances it is acceptable. Second, the solution can be used to study the question of whether the depth dependence of sediment properties can be determined or estimated by measurements of wave reflections. The reflection and transmission of waves at the water-saturated sediment interface have been studied by Stoll and Kan,¹⁸ but they did not include depth dependent properties. The depth dependence must be included in order to compare theoretical results to in situ measurements.

A preliminary study of this problem has been carried out. Consideration was given to several techniques for including depth dependence of the material parameters, including taking an integral

transform in the depth coordinate and treating the sediment as a layered medium. The approach that is currently favored is to numerically integrate the governing equations in the depth direction, assuming a layer of sediment material overlays an elastic substrate. A computer code has been written and has been used to verify the results of Stoll and Kan. It is expected that this work will continue in 1983 with a comparison of the results of the Biot-Stoll model to those obtained using a simple viscoelastic model.

III. LABORATORY STUDIES

The Biot-Stoll⁶⁻¹² model is a continuum theory for a viscoelastic, granular material, saturated by a compressible fluid. It has successfully predicted the frequency dependence of the phase velocity and attenuation observed in ultrasonic measurements in saturated sediments.

ARL:UT has devised an experiment which provides a critical test of the Biot-Stoll model. A model sediment consisting of glass beads is saturated by a mixture of water and glycerine. By varying the proportions of water and glycerine, the density, bulk modulus, and viscosity of the saturating fluid can be changed. Since all of these parameters appear explicitly in the Biot-Stoll model, it should predict the effects of the varying concentration.

Two sets of experimental measurements have been carried out. The first set¹⁹ indicated that the attenuation of both compressional and shear waves increased with increasing glycerine concentration (increasing fluid viscosity) much faster than the theory predicts it should, which raised questions about the viscous damping mechanisms in the theory. In an effort to verify these results, a second set²⁰ of measurements was taken. These still indicate a greater increase in attenuation than is predicted by the theory, although the discrepancy is smaller. The two sets of measurements are not directly comparable since two different grain sizes were used.

Thus, two sets of data on two materials exist, neither of which is consistent with the Biot-Stoll model. Because of the implications of

this data for future use of the model and the importance of this type of experiment, it is essential that additional data be obtained and that efforts to refine the experiment be continued. In particular, the experiments should be directed toward determining modifications that may be required in the Biot-Stoll model.

During 1982, further work was done to refine the experimental procedures in preparation for a third set of measurements to resolve discrepancies between the first two. Measurements of the radiation pattern of the transducers were obtained and alternate electronic configurations were evaluated. It is expected that the experiment will be conducted in 1983.

IV. HYDRATED MARINE SEDIMENTS

One feature that is rarely included in geoacoustic profiles of the ocean floor is the presence of natural gas hydrates in marine sediments. Hydrates are icelike crystalline structures that can significantly alter geoacoustic parameters²¹ such as shear and compressional velocities and absorption. The acoustic behavior of hydrated marine sediment can differ greatly from that of nonhydrated sedimentary sequences.²² Recent calculations²² indicate that bottom loss from hydrated marine sediments is particularly sensitive to the as yet unknown values for shear velocities.

Potentially favorable conditions for the formation of hydrate zones exist over 90% of the ocean floor and to a considerable depth in the sediment.²³ Recent evidence indicates the presence of massive quantities of gas hydrates in a variety of sedimentary sequences.^{24,25}

In FY82, ARL:UT designed²⁶ an experimental apparatus and developed an experimental plan to measure the acoustical behavior of marine sediments bearing gas hydrates. The goal of the experimentation is to obtain values for shear and compressional velocities in a variety of hydrated sediments. The apparatus consists of an acrylic vessel designed to contain sediments and gases under sufficient pressure-temperature conditions to form gas hydrates. Xenon gas will be used initially to form the structure I hydrate, followed by the use of propane gas which forms the structure II hydrate. Both of these structures occur in marine sediments. The low dissociation pressures of xenon hydrates (1.5 atm) and propane hydrates (1.74 atm) will enable a safe and efficient performance in the laboratory environment. The vessel is designed for installation of instrumentation capable of

measuring the acoustical, thermal, and electrical properties of gas hydrates in sediments.

The experiment will be conducted in three phases. In the first phase, the apparatus will be constructed and the procedure for growing hydrates will be developed. In the second phase, the apparatus will be modified according to suggestions arising from the first phase and the apparatus will be adapted for acoustical measurements. The procedure for measuring the acoustical parameters will then be developed. In the final phase, an extensive set of measurements will be taken in which the sediment type, pressure-temperature conditions, and hydrate concentrations will be varied over a wide range in order to determine their influence on the acoustic parameters.

V. SUMMARY

In 1982, the ARL:UT program worked in three areas. The first area involved theoretical analyses of two subjects: (1) propagation in sediments containing gas bubbles and (2) the comparison of Biot and viscoelastic treatments of reflection from sedimentary material. The second major research area was an experimental program to verify various aspects of the Biot treatment of propagation in marine sediments. In particular, the dependence of shear and compressional velocities and absorptions on viscosity was measured and compared to Biot theory predictions. The third major area was the design of an experiment to measure the acoustical properties of hydrated marine sediments. Each of these areas produced tangible results in the form of reports or journal articles.

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